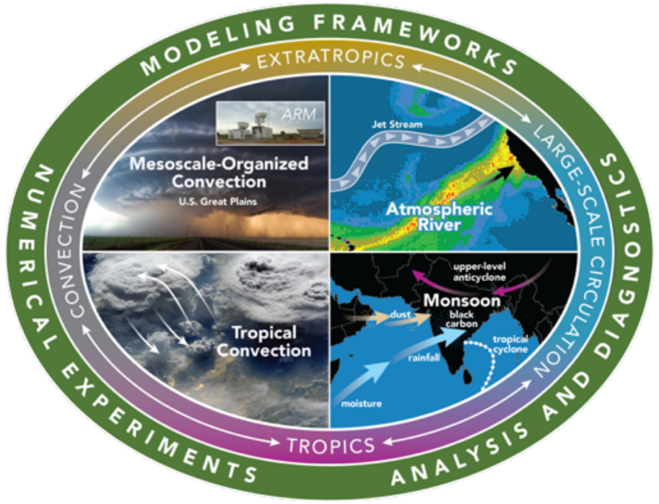
Overview of the Water Cycle and Climate Extremes Modeling (WACCEM) SFA

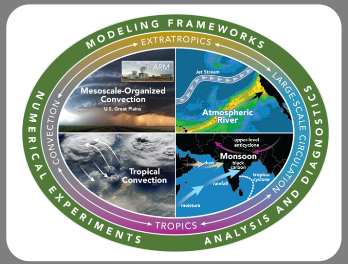
L. Ruby Leung

Pacific Northwest National Laboratory

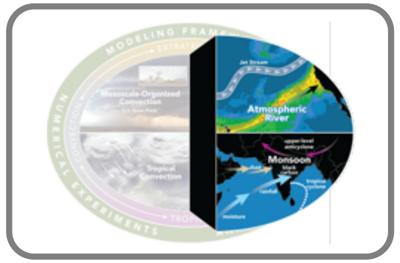
DOE RGMA PI meeting
October 13-16, 2020



WACCEM research in FY19-21



To advance robust predictive understanding of water cycle processes and hydrologic extremes and their multi-decadal changes

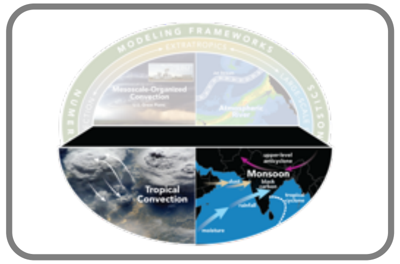


Large-scale circulation

- Monsoon-ITCZ from an energetic perspective
- Predictability of atmospheric rivers and extreme precipitation
- Baroclinic annular mode and subseasonal precipitation variability

Mesoscale convection

- Global characteristics of mesoscale convective systems (MCSs)
- Large-scale environments of MCSs and future changes
- MCSs, hydrologic footprints, and land-atmosphere interactions



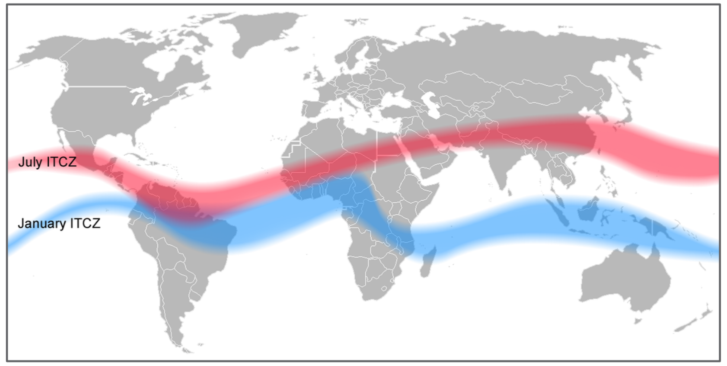
Multiscale convection-circulation interactions

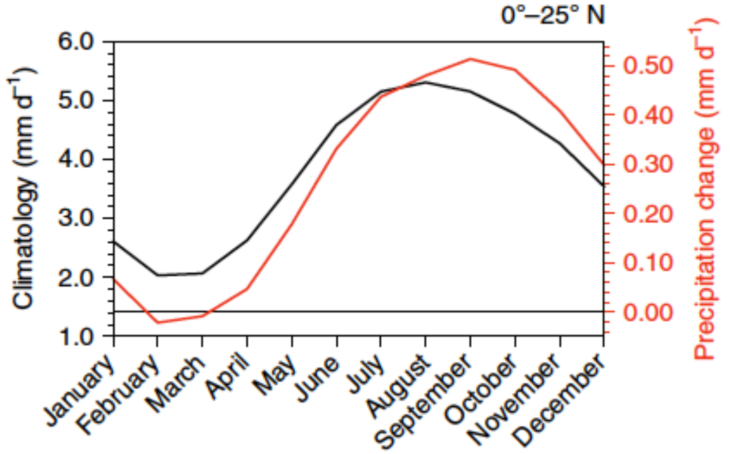
- Role of convection in tropical overturning circulation
- Subseasonal variability of convection and MJO
- Connections between MJO, atmospheric rivers, and tropical cyclones

Large-scale circulation

Tropical precipitation seasonal cycle changes

Seasonal phase delay in tropical precipitation associated with an inter-seasonal change (AMJ-JAS) in latent heating driven by warming

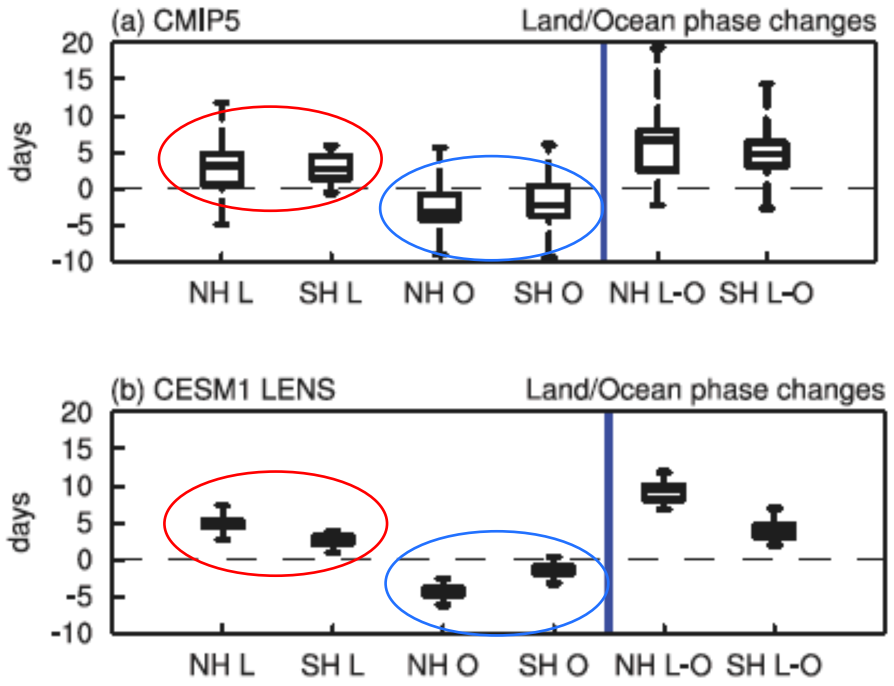




Tropical precipitation climatology and future change

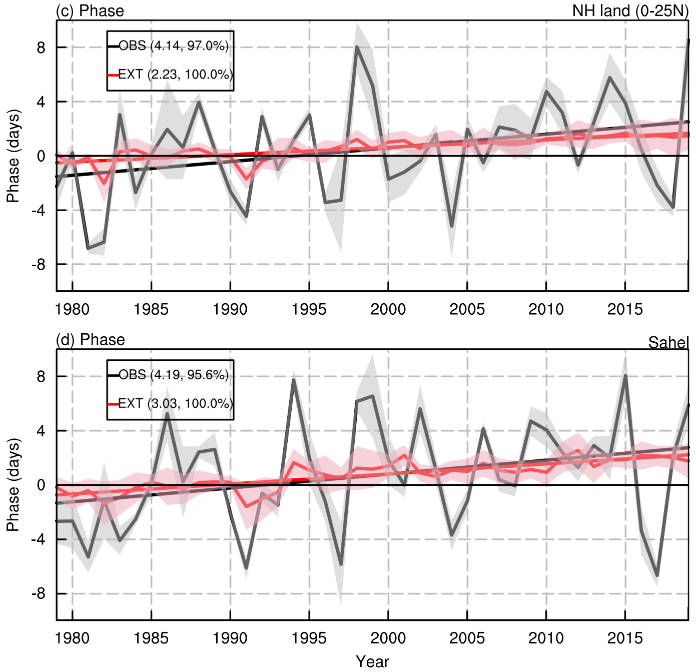
(Song et al. 2018 NCC)

Contrasting precipitation seasonal cycle phase changes over land (delay) and ocean (advance) under warming

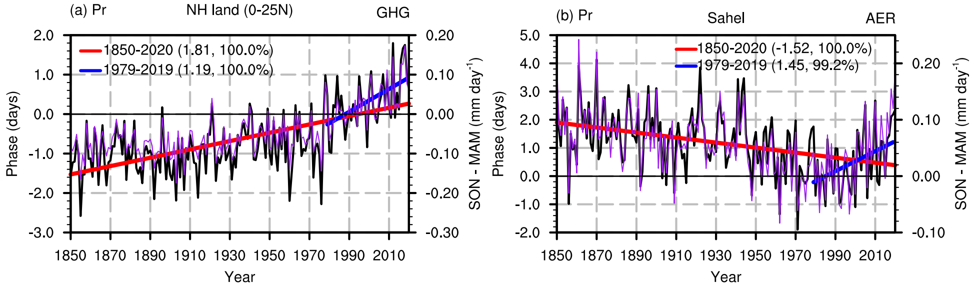


(Song et al. 2020 GRL)

The seasonal delay over land has already emerged in observations (1979-2019)

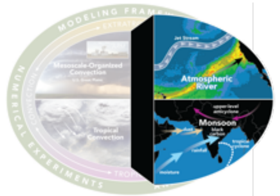


GHG increase and AER decrease delay the annual cycle of precipitation, with GHG more important over NH tropical land and AER more important over the Sahel



(Song et al. in review)

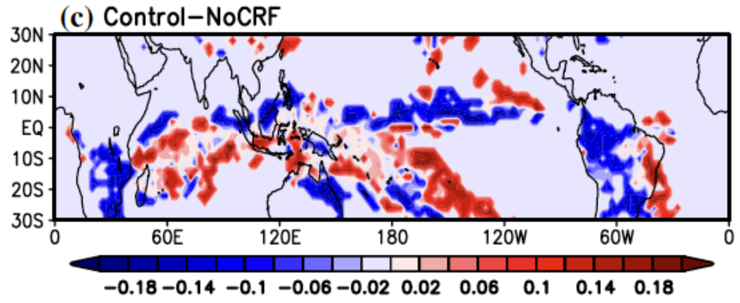
(*Synoptic/intraseasonal breakout session)



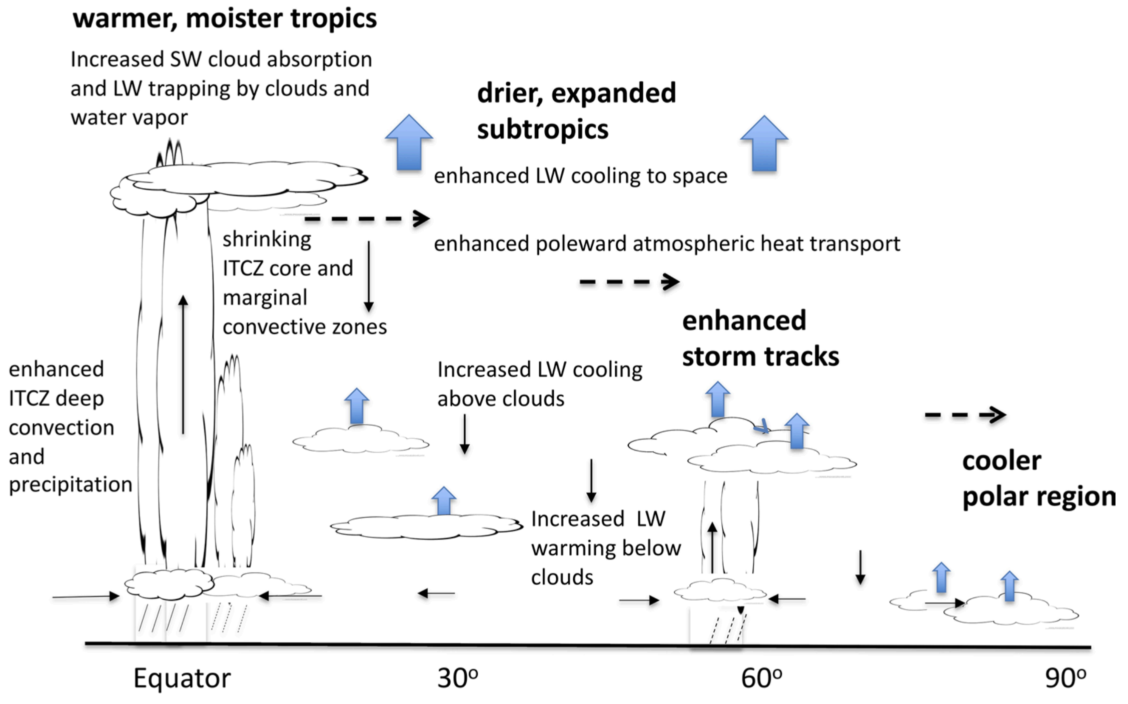
ITCZ changes and role of cloud-radiation interactions

Radiation-cloud-convection-circulation interactions (RC3I) induce structural changes and variability in the ITCZ from MMF simulations

Perform a set of E3SM and MPAS-A simulations to clarify the role of RC3I on the ITCZ and its future changes

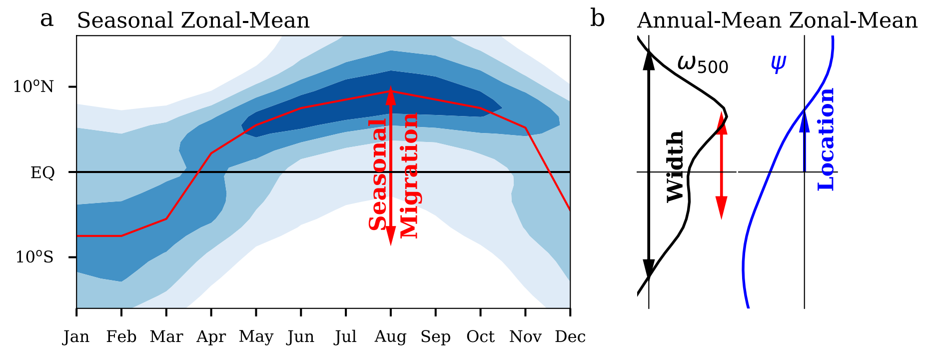


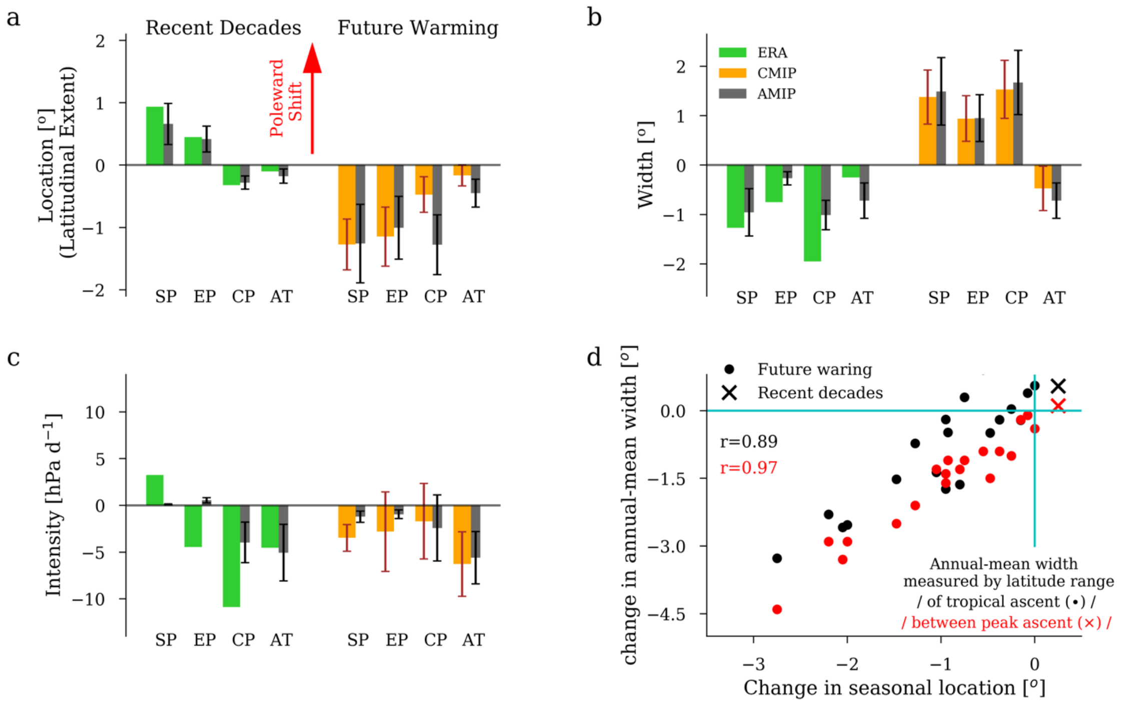
Changes in 500 hPa w with and without RC3I suggest convective aggregation



(Lau et al. 2019 CLIM DYN)

The seasonal ITCZs have shifted poleward and narrowed in recent decades but are projected to shift equatorward and widen under future warming

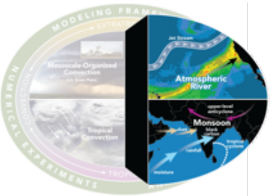




Equatorward shift of the seasonal ITCZ is correlated with the narrowing of the annual mean ITCZ

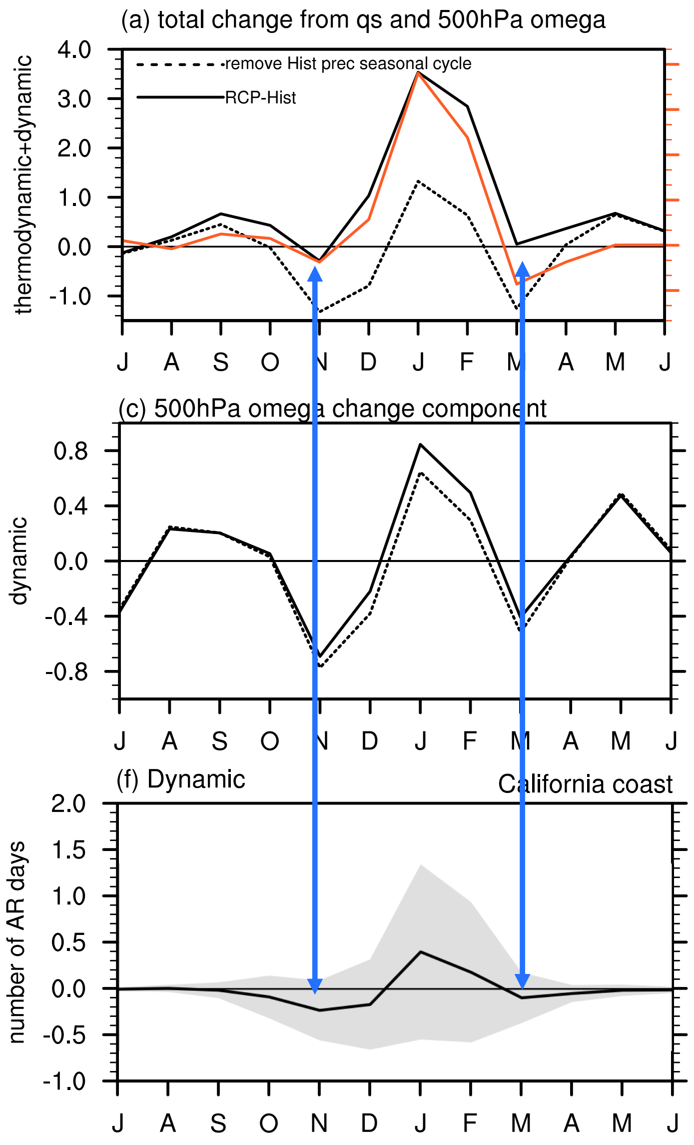
(Zhou et al. in review)

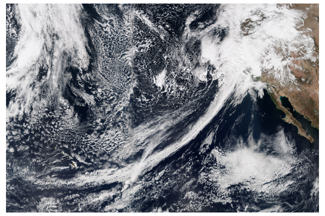
Large-scale circulation



California precipitation seasonal cycle changes

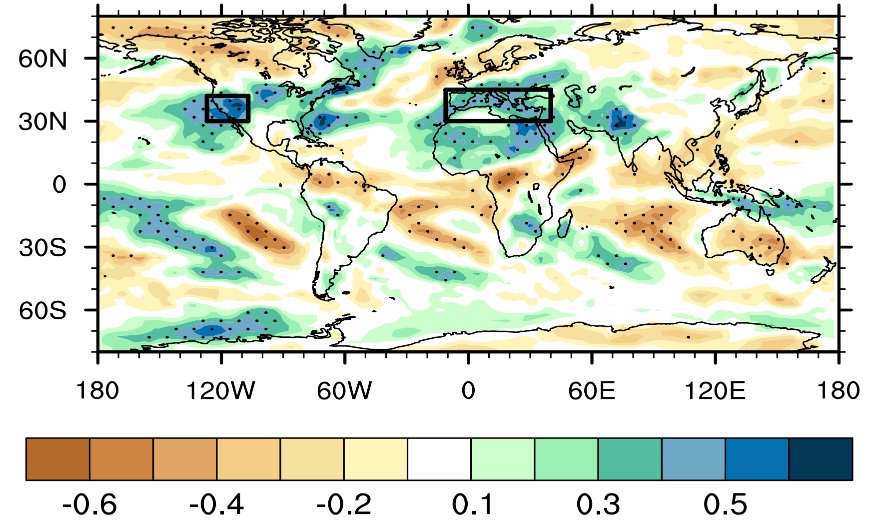
A robust signal in sharpening of CA mean (20/23) and extreme (21/23) precipitation seasonal cycle, consistent with the sharpening of seasonal cycle of atmospheric river frequency

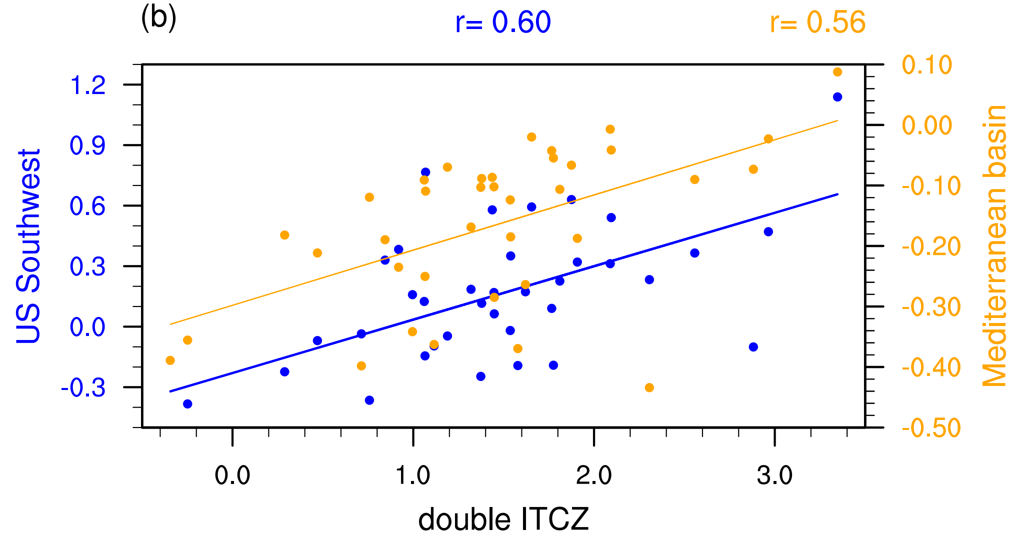




(Dong et al. 2019 GRL)

Models with larger double-ITCZ biases tend to exaggerate the wetter winter over southwestern US and understate the driver winter in the Mediterranean Basin in the warmer future



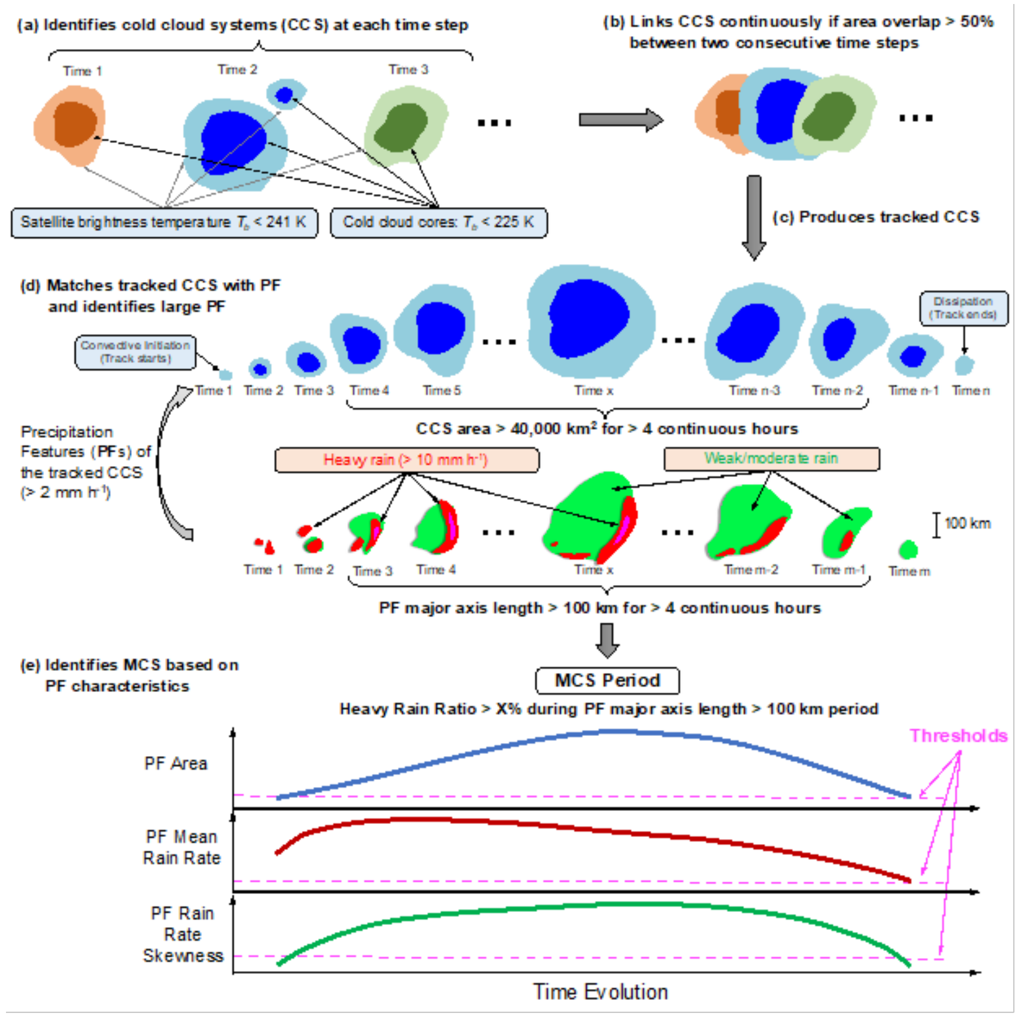


(Dong et al. in review) (*Earth system predictability breakout session)

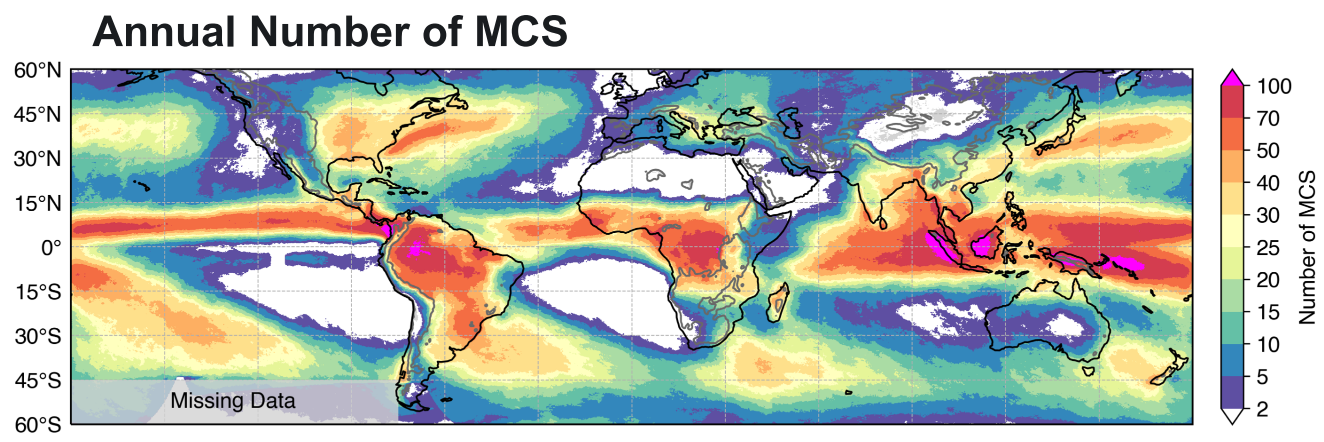
Mesoscale Convection

MCS tracking methods and datasets

FLEXTRKR has been updated for global MCS tracking using satellite brightness temperature and IMERG precipitation



(Feng et al. in prep.)



Dataset development

- A 1/8° hourly MCS data for the US based on T_b and NLDAS precipitation (1979-2018)
- A 4-km hourly MCS data for the US based on T_b and NEXRAD radar reflectivity and Stage IV gridded precipitation (2004-2017)
- A ~10-km hourly global MCS data based on T_b and IMERG precipitation (2001-2019)
- An MCS dataset based on an ensemble WRF-EnKF simulation for YOTC
- GPM radar precipitation feature
- NOAA storm event database
- USGS streamflow records

MCS characteristics, environments, and impacts

- MCS statistics including diurnal, seasonal, interannual variability
- MCS lifetime, propagation speed, volumetric rainfall, convective and stratiform area
- MCS latent heating profile
- MCS large-scale environments and precursors
- MCS flooding and roles in land-atmosphere interactions

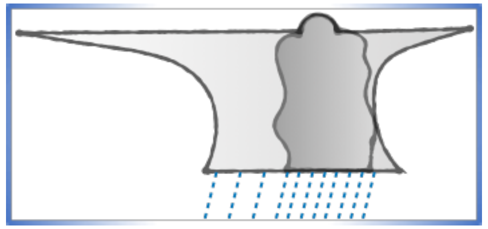
(Feng et al. 2016 NCOMM; Feng et al. 2018 JAMES; Feng et al. 2019 JCLIM; Liu et al. in prep.)

(*Convection breakout session)

Mesoscale Convection

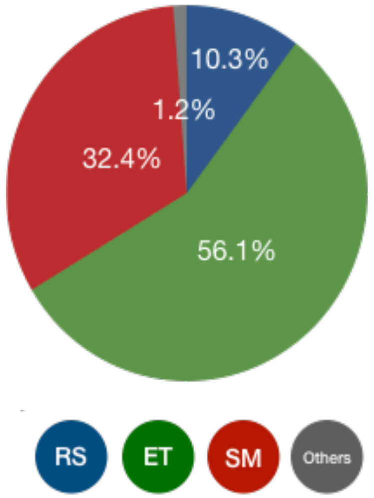
MCS land surface footprints and roles in soil moisture-precipitation feedback

MCS produces more intense rain with larger rain area

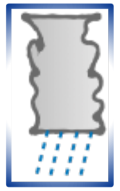


Larger contribution to runoff

(a) MCS rainfall partitioning

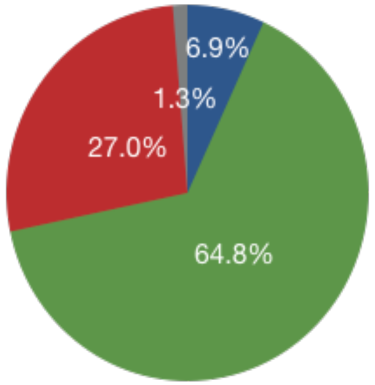


Non-MCS rain occurs more frequently in space and time



Larger contribution to ET

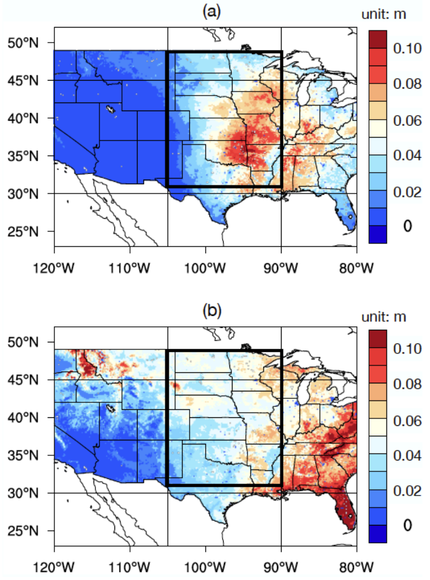
(b) non-MCS rainfall partitioning



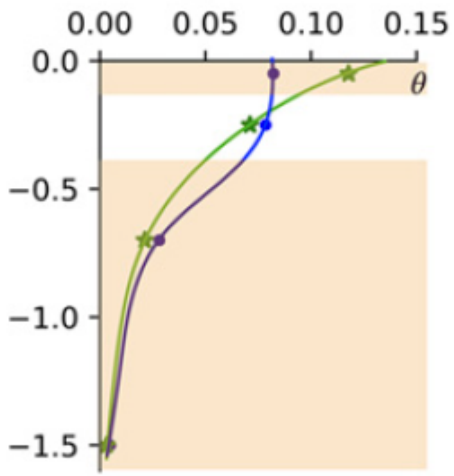
(Hu et al. 2020 GRL)

(Hu et al. 2020 JHM)

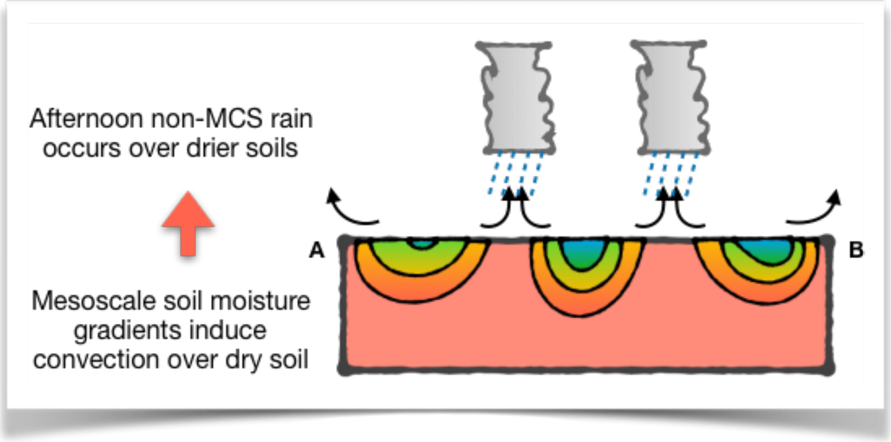
MCS rain produces larger soil moisture anomalies with stronger gradients



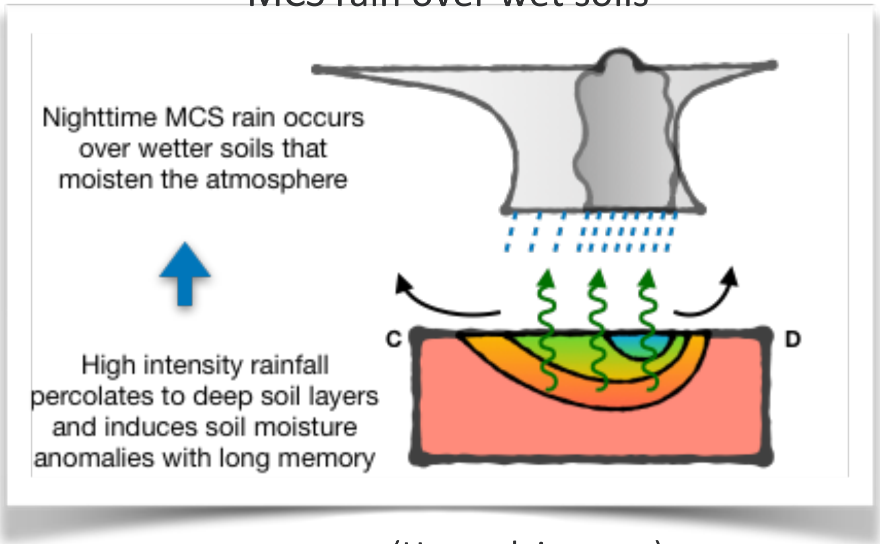
MCS rain percolates deeper in the soil layers with longer memory



Earlier season MCS rain favors summer non-MCS rain over dry soils



Earlier season MCS rain favors summer MCS rain over wet soils



(Hu et al. in prep.)

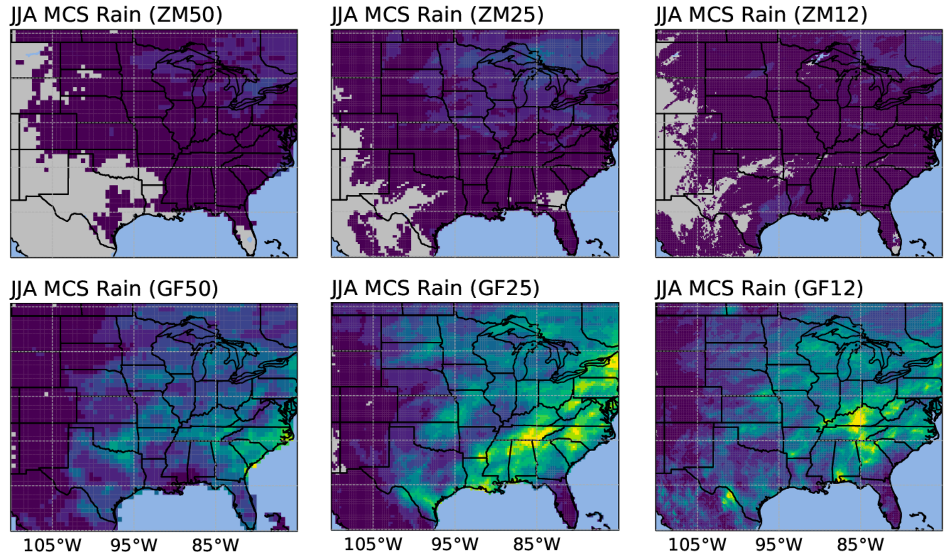
Mesoscale Convection

MCS modeling: convection permitting modeling, convection parameterizations, model evaluation

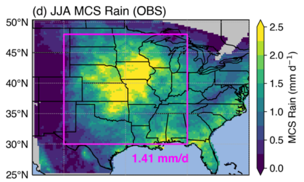
The Grell-Freitas scheme significantly improves MCS simulation compared to the Zhang-McFarlane scheme in MPAS-CAM5

ZM

GF



OBS

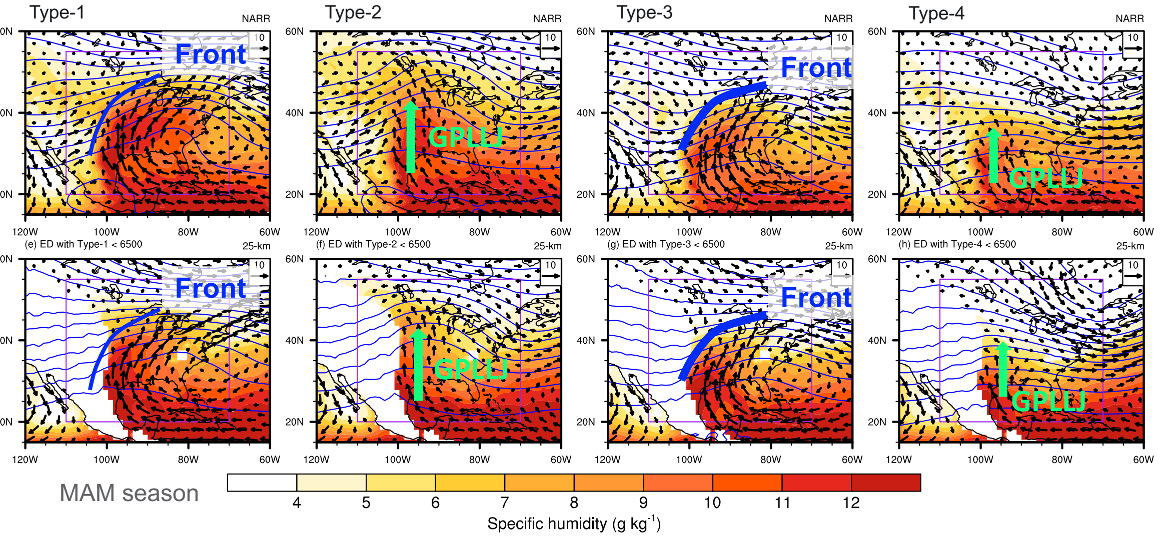


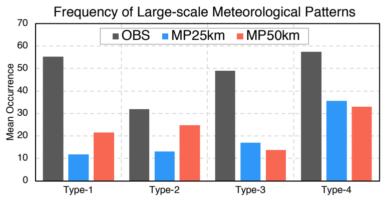
(Sakaguchi et al. flash talk)

MPAS-CAM5 produces the MCS large-scale environments but at significantly lower frequency

OBS

MPAS-CAM5

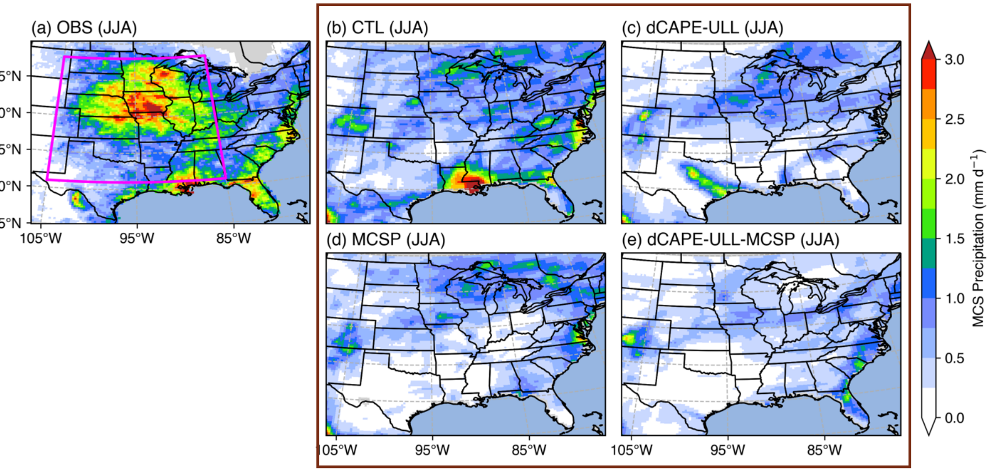


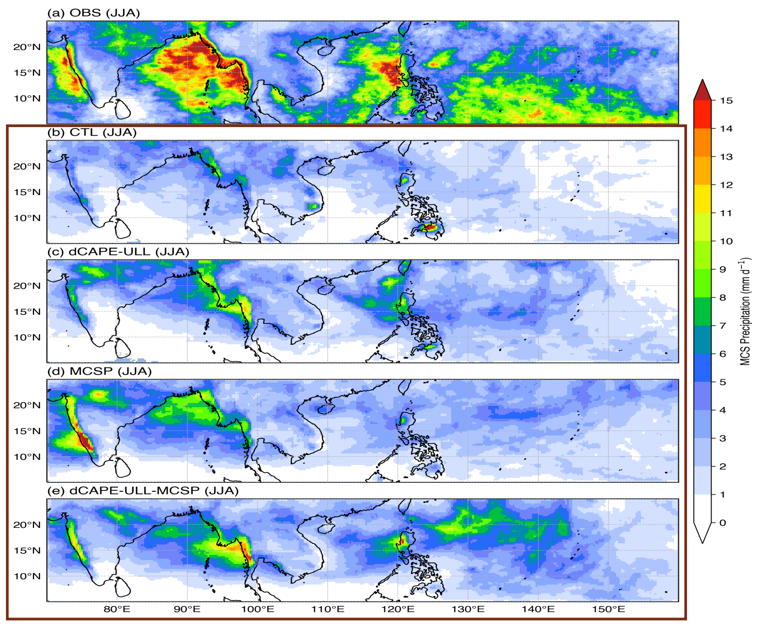


(Song et al. 2019 JCLIM; Feng et al. 2020 JCLIM)

In collaboration with the E3SM team, evaluate new developments of convection and cloud microphysics schemes for improving MCS simulation in E3SM

Observed and simulated MCS precipitation





Multiscale Interactions

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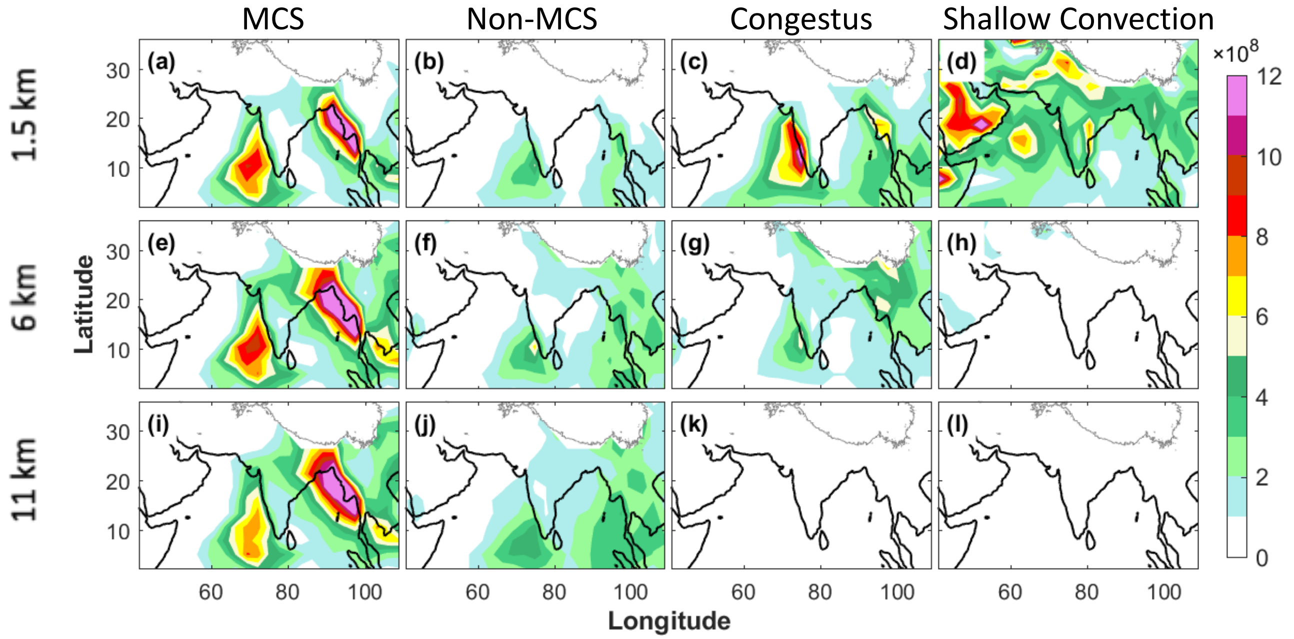
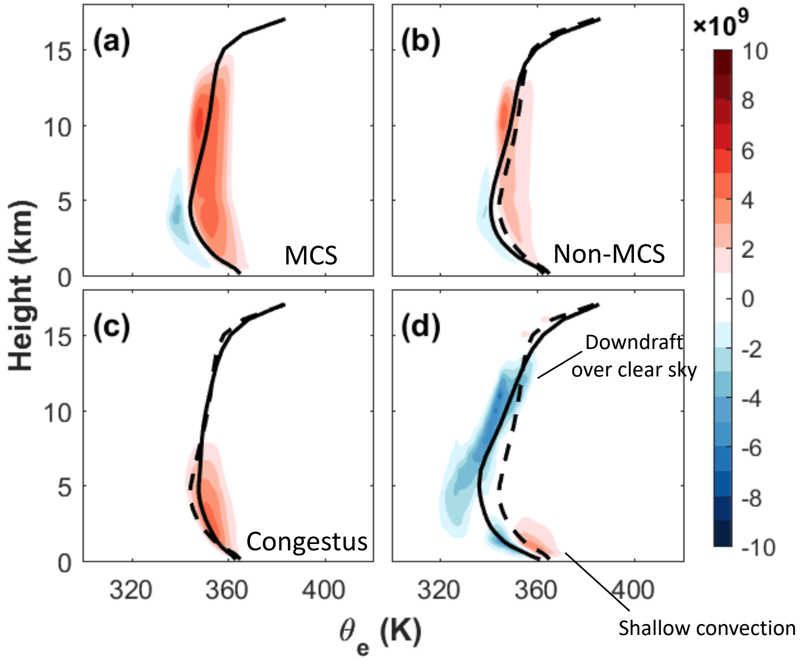
Overturning circulation of different cloud types

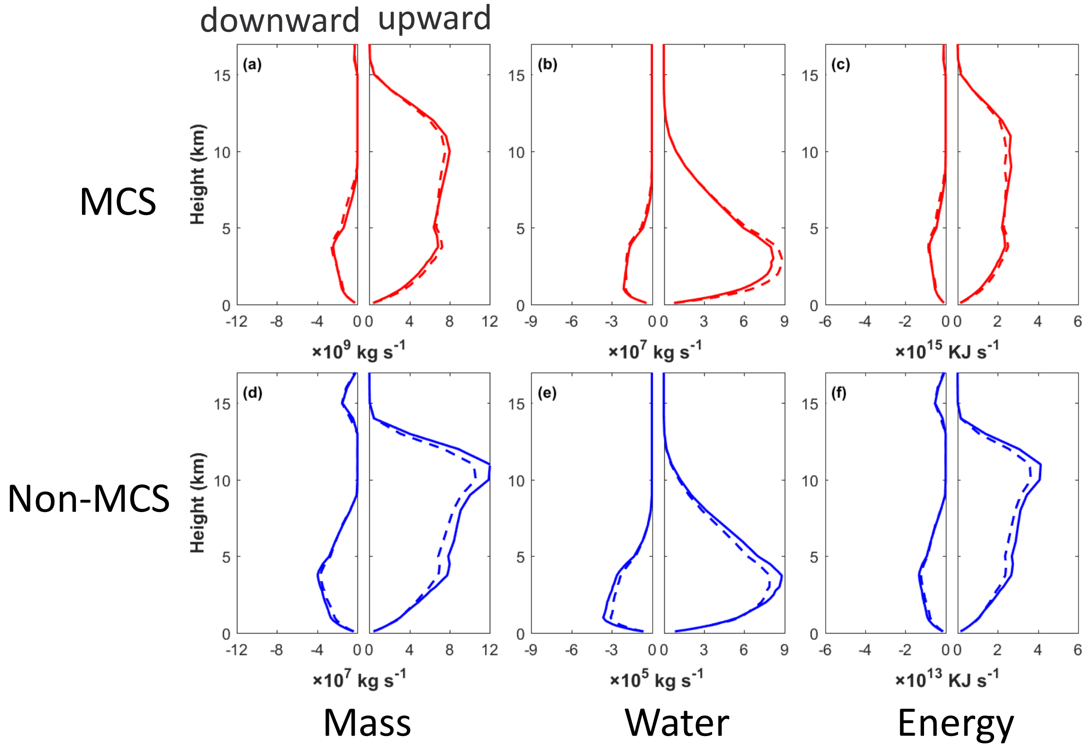
Isentropic analysis of a WRF simulation at 4.5 km grid spacing without CP shows regions of strong upward mass transport dominated by MCS in the upper troposphere



(Chen et al. in prep)



Isentropic distributions of total mass flux (kg s^{-1} K^{-1}) averaged over the Indian summer monsoon season (JJA)

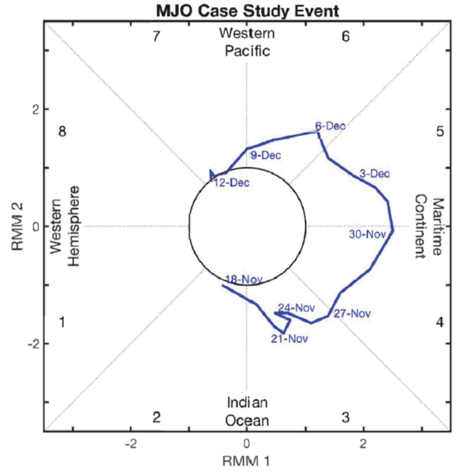


Per event, MCS vertical transport of mass, water, and energy is 70 to 100 times that of non-MCS deep convection

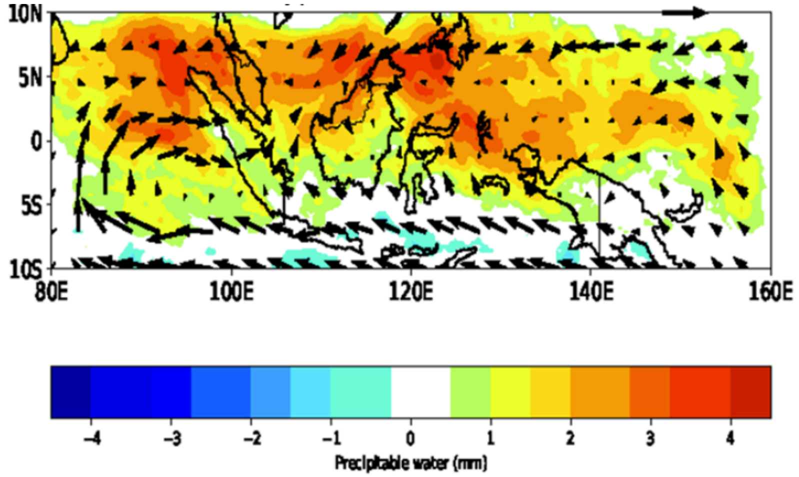
Multiscale Interactions

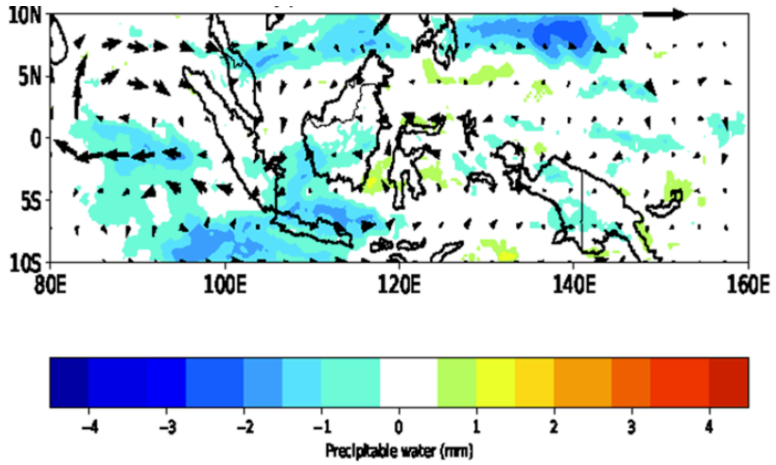
MJO propagation and impact on landfalling atmospheric rivers

Propagation of the MJO across the Maritime Continent impacted by solar insolation that influences the basic state moisture



Convection permitting simulations of the November 2014 MJO show that increased insolation due to seasonal variations increases precipitation over the Maritime Continent by increasing the basic state moisture rather than the MJO responding directly to the insolation change

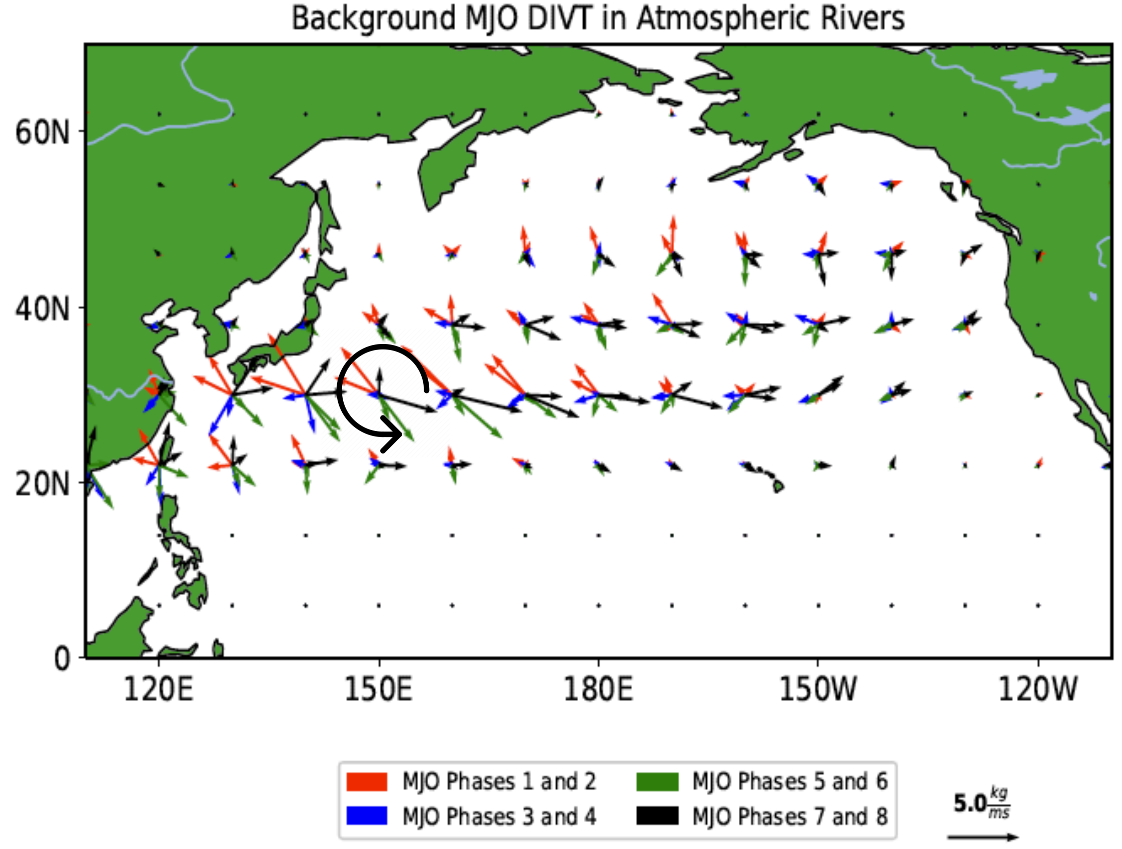




(Hagos et al. 2020 JGR-A)

Different phases of the MJO modulate the background divergent integrated vapor transport (DIVT) and influence the likelihood of atmospheric river landfall in the US west coast

Counterclockwise rotation of background DIVT with MJO phases – AR landfall most likely in phases 7 and 8 with eastward moisture transport

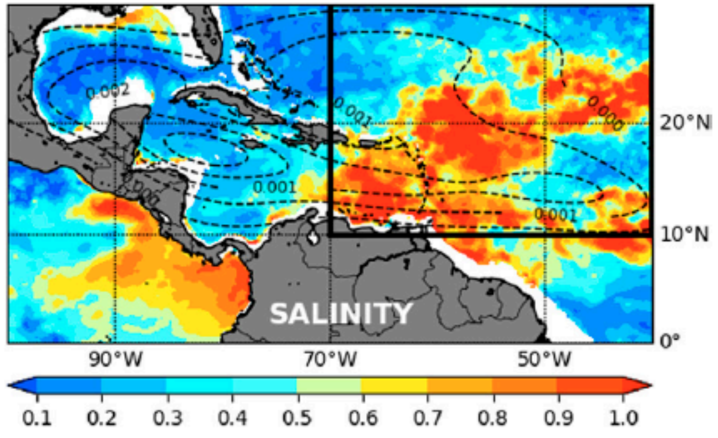


(Hagos et al. in review)

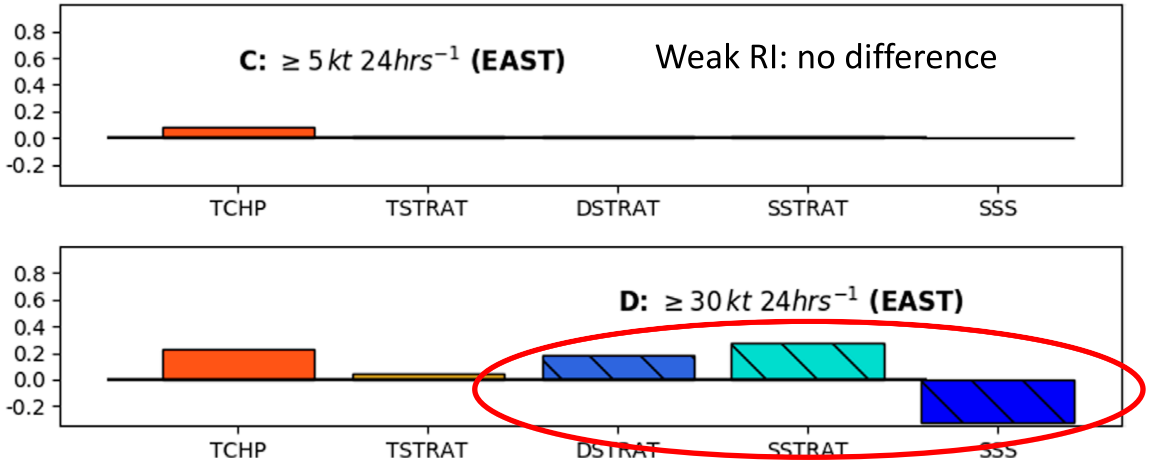
Multiscale Interactions

Effects of air-sea interactions on tropical cyclone intensification and activity

Inclusion of satellite surface salinity significantly improves rapid intensification (RI) forecast



Difference between TC locations with RI above certain thresholds and all TC locations

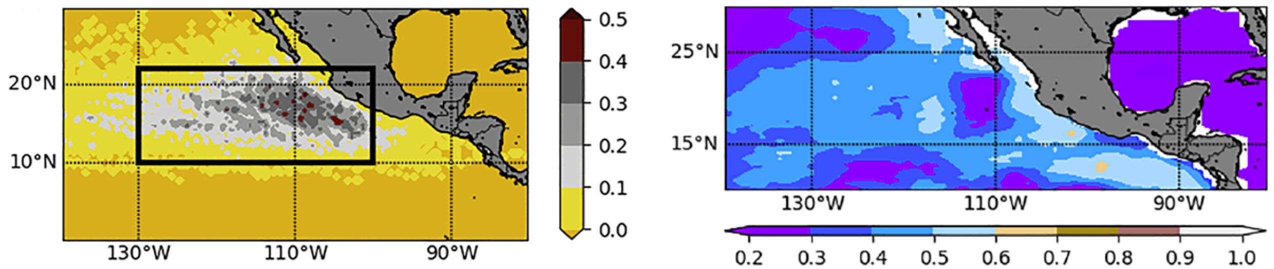


Strong RI: salinity related quantities matter

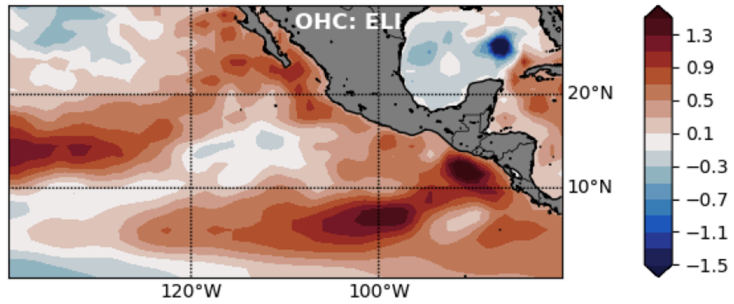
(Balaguru et al. 2020 BAMS)

The ENSO Longitude Index (ELI) that better captures the changes in the locations of deep convection and thermocline processes during El Nino better explains TC activities in eastern North Pacific with lead times of several months

ENSO influences TC activity through changes in ocean heat content in the eastern North Pacific (high correlation between ACE and dynamic temperature (Tdy)



E3SM captures the anomalous ocean heat content during strong El Nino years defined by ELI



(Balaguru et al. 2020 GRL)

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PNNL team and collaborators

PI and Research Element Leads

Leung (PI)

Hagos

Lu

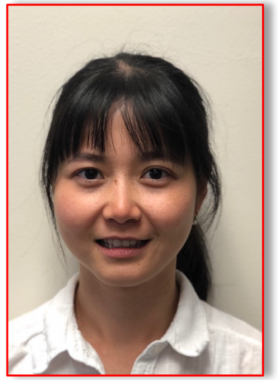
Balaguru

Dong

Feng

Harrop

Hu



Krishnakumar

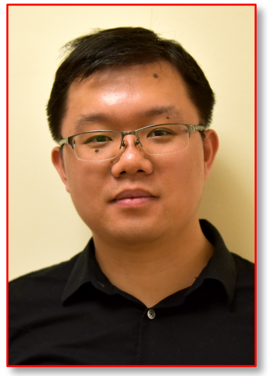
Liu

Sakaguchi

Song

Teng

Yang

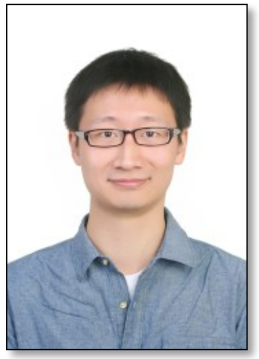


Zhou

Lau, UMD

Skamarock, NCAR

Chen, PSU



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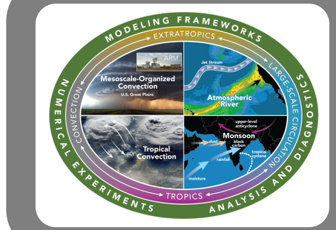
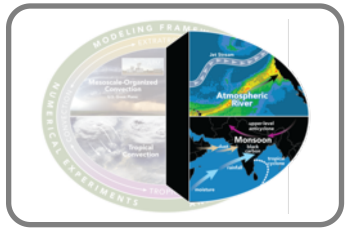
Questions?



To advance robust predictive understanding of water cycle processes and hydrologic extremes and their multi-decadal changes



Large-scale circulation

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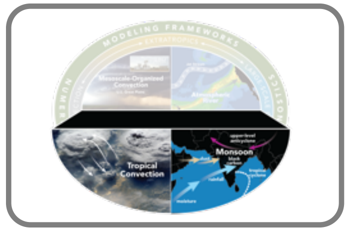

Multiscale convection-circulation interactions

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